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Art. V.—*The Mineralogical Characters of Victorian Auriferous Occurrences.*

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The contributions of various authors to the Mineralogy of Victoria have included records of a large number of minerals from the quartz reefs and other auriferous matrices (see especially references 1 to 4 below). In some cases the associations in which the minerals occur are described, and their bearing on the gold-contents noticed. It was early seen that certain minerals were present on nearly all the Victorian goldfields. This prevalence of the one mineralogical type, even in cases where structural features were widely different, has perhaps been one cause of the scantiness of the attention given to the mineralogical characters of the gold occurrences.

In these notes a classification is presented of the mineral associations which are found in our known auriferous matrices and allied mineral deposits. Some occurrences are included which are not proved to be auriferous or whose gold contents are even known to be unimportant, but which occur under conditions analogous to some auriferous lodes or approach them in their characters.

For the basis of the classification I use the predominant minerals among the sulphides, etc., of the ore as unaltered by surface agencies. A bare list of minerals present in any reef or in any field will not adequately represent the character of the ore, as is exemplified by Groups 1 and 2 below. The number of minerals found in a reef is sometimes considerably increased by the minerals noticed in some peculiarly complex patch. Minerals placed below as two distinct groups may be found together in the one reef, though often occurring independently of one another, this is especially the case when the groups ordinarily occur under similar conditions. It may also happen that what appears to be one reef may consist of parts of quite different mineralogical types.

The following mineral associations may be recognized, being characterized by the presence or prominence of the minerals mentioned in each case.

1. The ordinary type.—Pyrite or arsenopyrite or both, prominent among the metallic compounds; with sphalerite and galena commonly present in small quantities.
2. Galena and sphalerite prominent with pyrite.
3. Stibnite.
4. Chalcopyrite.
5. Siderite and chalcopyrite.
6. Pyrrhotite and chalcopyrite.
7. Molybdenite usually with pyrite.
8. Bismuth minerals.
9. Wolfram.
10. Cinnabar and mercury.

1. The association of minerals in this type, as ordinarily occurring, may be more fully stated as quartz, albite, dolomite, pyrite, arsenopyrite, galena, gold. Carbonaceous matter is also frequently present, sometimes as graphite.

The albite and dolomite are quite subordinate to the quartz in quantity. The sphalerite and galena, though in much less quantity than the iron minerials, and less generally distributed in the reef, are often persistently present in the richer portions. Of the two iron compounds one or other may be more prominent, or both equally so. The proportion of the metallic minerals in the reef varies greatly. There are of course many reefs of this type from which a part only of the series is recorded.

Dolomite and albite often escape notice in the bad light in the mine, but are easily recognised in most cases by their cleavages. Albite is often altered to kaolin to a considerable depth from the surface, and pholerite also occurs in the cavities of the quartz. Dolomite is often evident on the old material on the mullock heaps, as it contains a little iron carbonate which causes it to turn brown on exposure. In the Ballarat mines it occurs in four forms, impure grey dolomite in the country rock agreeing with the bedding planes or nearly so; brownish granular masses; veins in the quartz and country rock and patches in the quartz, these show district cleavage; and crystals in the cavities of the quartz. Albite and dolomite are not by any means confined to Ballarat but are widely distributed in occurrences of this type. Albite is less often recorded but this is easily accounted for by its frequent alteration and its less easy recognition.

Carbon occurs in the carbonaceous slates of the country rock, on the walls of the reefs which not infrequently follow the course of these carbonaceous slates, and as the laminations or fine sub-parallel seams in the quartz. In some cases these laminations consist in part of other minerals. Highly lustrous graphite appears to be found chiefly on the planes of movement and in rocks which have undergone more than the usual amount of alteration, as at Stawell and at Piggoreet.

Order of Crystallization.—Cavities containing quartz crystals are not uncommon, and in these we find the quartz often invested by dolomite and pyrite crystals implanted on the dolomite. These crystals are often in pyritohedral forms, whereas in the reefs distinct crystals are not common, and in the country rock they are most commonly cubes. Elsewhere (Dee River, Queensland) we have evidence of gold-nuggets moulded on quartz crystals (7), but the large masses of gold found on the indicator veins are commonly mixed with the vein quartz.

We find, however, evidence of dolomite preceding quartz as well as following it, and pyrite is found enclosed both in quartz and in dolomite.

Crystals of arsenopyrite are found in the country rock at Mt. Pleasant, Ballarat, invested by a thin layer of quartz.

Commonly no growth lines in the quartz are detected nor any crustified character in the reefs. The laminations of the reefs often noticed may be referred to the disposition of the quartz along a series of sub-parallel cracks in the original rock, or in a fault-rock, and the formation of mullocky reefs may be ascribed similarly to deposition on numerous cracks traversing shattered rocks.

We may regard as original the carbonaceous matter of the laminations and probably the grey granular dolomite bands such as occur at Ballarat East. The pyrite and arsenopyrite of the country rock and the minerals of the reefs may be regarded in the present state of our knowledge as practically contemporaneous. It must, however, be remembered that the quartz reefs of the one field are in some cases of appreciably different ages, as indicated by their relations to one another and to faults. The order of succession in the cavities must not be given too much weight in determining the general process of growth of the reef.

The masses of gold on the indicators should also receive separate investigation from the ordinary reef. To whatever extent the indicator gold may be secondary (whether that term is used with reference to the time of its formation or to its being regarded as subordinate to a general theory of vein formation), it cannot be referred to any process of surface weathering, for these rich patches are associated with easily decomposable minerals, and their characters are continuing unchanged in the deepest levels at Ballarat East.

The mode of association with other minerals and with the quartz also renders impossible any formation by a process of filtration such as recently suggested by one writer (8). Nor can they be due to obstruction to the motion of solutions in view of the nature of the general resistance to the motion of solutions through the fractures and the rocks themselves, for they are in many cases in places where the movement would be easier than usual.

Whatever may have been the sources and the general causes of the deposition of the minerals of the reefs, there is strong evidence that the position of the richer gold contents has been determined by the presence of carbonaceous matter, or at least of certain favourable slates, which are frequently carbonaceous. We find the saddle reefs of Bendigo following the course of carbonaceous beds on which there has been slipping (15). The veins of Ballarat East are often rich in crossing thin carbonaceous beds, and the so-called main reefs of the same field are richest in certain favourable slates. In many localities veins are found along the course of the carbonaceous slates, and richest in their laminated parts. The easiest explanation of the indicator masses seems to be to regard them simply as the extreme case of this more widespread feature where the favourable bed is most restricted, and the access of the solutions, by a crack nearly at right angles to the indicator, is at the same time facilitated and most definitely localised. Slipping on the carbonaceous bed might then contribute by rendering more easy the percolation of solutions along the beds, providing thus a more ready supply of the active ingredient of these impermeable beds.

Extensions and modifications of the first type. At places in a reef there sometimes appear small quantities of additional minerals. Thus from the Albion Reef, Steiglitz, Ulrich records (2) stibnite, tetrahedrite, and bournonite, with pyrite, sphalerite, gold and pholerite in the hollows of the quartz. The tetrahedrite contains arsenic, iron and zinc. From the Band and Albion Mine, Ballarat, Krausé records (5) calcite, dolomite, siderite with pyrite, chalcopyrite and tetrahedrite. Boulangerite and bournonite have also been recorded from Ballarat, but all these are rare.

Chalcopyrite occurs at a number of localities, according to Mr. R. H. Walcott, more especially Eastern Victorian (4). Mr. H. S. Whitelaw (9) describes the best reefs at Berringa as containing galena and chalcopyrite. It appears to be much commoner there than at Ballarat. Mr. O. A. L. Whitelaw (16), states that the minerals accompanying the lodes at Wood's Point are mainly pyrite and galena, with smaller quantities of sphalerite, copper carbonates and jamesonite. Mr. D. Clark (6) states that in the Cassilis ore, where the sulphides form from 10 to 60 per cent. of the ore, arsenopyrite is most prominent with pyrite, sphalerite, galena, chalcopyrite and small quantities of stibnite and bismuthinite. Magnesium and aluminium silicates are present in this ore. At the Maude and Homeward Bound Mine, Mount Wills, pyrite and arsenopyrite are accompanied by a little stibnite and a silver sulphantimonite.

The Bethanga ore contains the ordinary minerals of the first type of occurrence with the addition of those mentioned below as group 6, chalcopyrite and pyrrhotite, in quantities exceeding the sphalerite and galena (6). The Maldon field gives many examples of the addition of the same two minerals, according to the report of Mr. R. A. Moon (10), with the addition of a variety of other minerals, more especially those usually found near granitic rocks. Native antimony, stibnite and jamesonite are recorded from this field. A number of the rarer minerals here are found in veins separate from those of the ordinary type as noticed below. A remarkable variation is found near the great vugh of the Eaglehawk Reef, Maldon, the quartz being replaced by cacholong or common opal, in which were garnet, amphibole, ferrocalcite, arsenopyrite, galena and sphalerite.

Indication of gold by the minerals of the reef.—The association of richer portions of the reefs with carbonaceous material has already been noticed. With regard to the minerals of the reef themselves, it is often difficult to get exact information as to their bearing on the gold contents. It remains an open question in many cases whether the greater richness in gold is connected with the appearance of certain definite minerals or with the general increasing complexity of the mixture. An increase in the amount of the sulphides is usually accompanied by increased gold contents.

The appearance of sphalerite or galena in a reef of this type is always regarded as an indication of probably better grade stone. Opinions differ, however, as to which of these is the better, but the balance is in favour of the sphalerite. I have only once heard of an instance in which this mineral was not regarded favourably, and, in this case, the information was not very reliable or complete. It should be remembered that this mineral, being the lightest of the metallic minerals in this type of ore, is less readily saved by the ordinary processes, and its pale and lustreless appearance when crushed renders its loss less easily detected. At Maldon, according to the report already quoted (10), arsenopyrite, sphalerite, and stibnite are regarded as the most favourable to good gold. Pyrrhotite according to the same authority is good in small quantity, but in larger quantity usually bad. Ulrich (1) quotes assays from the wall of the Tiverton Reef, Maldon, as giving from material containing pyrrhotite, 2 to 10 oz. gold per ton.

Arsenopyrite seems to be usually more favourable than pyrite. A sample of slate from Ballarat East, without quartz, but with crystals of arsenopyrite, gave 3 oz. to the ton, and a roughly concentrated sample of arsenopyrite from it, 20oz. to the ton. The gold, if not in the arsenopyrite, was at least associated with it.

Mr. H. S. Whitelaw regards chalcopyrite and galena as constantly present in good gold-bearing stone at Berringa (9).

The alteration by surface waters of the minerals of these reefs gives rise to marcasite (which, however, is easily decomposed), melanterite from marcasite, copiapite; limonite; orpiment and realgar very rarely; scorodite probably much more often than recorded, pharmacosiderite, kaolin, pholerite, epsomite, and other minerals.

2. At St. Arnaud, Percydale, and other localities in the Pyrenees there is a great prominence of galena and sphalerite. Accompanying this there is, as might be expected, a larger proportion of silver in the output of the mines. Some parts of the ore yield concentrates which have been smelted for lead. The difference from the preceding type is the great quantity of these minerals which in the ordinary association of minerals are quite subordinate. In some samples of these ores the proportion of quartz also is comparatively small. The general result of assays at Percydale is said to have been that a large amount of galena tended to give high silver contents, and a large amount of sphalerite good gold contents in the ore. An assay at the Ballarat School of Mines of a sample from St. Arnaud containing galena, sphalerite, pyrite and arsenopyrite, with little quartz, gave: silver 19oz. 12dwt., gold 2oz. 19dwt. 11gr. per ton. From the Glendhu Reef, Landsborough, an assay of pyrite is quoted by Ulrich (1) as giving: silver 42oz. 9dwt. 14gr., gold 1oz. 4dwt. 11gr. The material is quoted as an example of pyrite rich in silver. It is not unlikely that it was originally associated with galena, and, if so, may be regarded as analogous to an instance from the Pinnacles, Barrier Ranges, given by Jaquet (11), where a mixture of galena and pyrrhotite had 75 per cent. of its silver in the pyrrhotite, though that mineral without galena was poor or barren.

The galena at Buchan, East Gippsland, where it is found nearly free from sphalerite, seems to contain very little gold. A sample of concentrates from the Buchan Proprietary Mine gave 55 per cent. lead, silver 21oz., gold 3dwt. per ton (12). A quartz veinstone from Gelantipy quoted in the same report gave, in different samples, up to 71 oz. of silver, but under 4dwt. of gold per ton in the highest assay.

At St. Arnaud bournonite occurs, and in the surface stone anglesite, cerussite, pyromorphite, mimetite, embolite and native copper.

3. Auriferous antimony ores.—Stibnite is only found in small quantities in the ordinary quartz reef, as in the instances already quoted. There are, however, a series of lodes in which it is the leading metallic constituent. These are mainly in the Silurian area of Central Victoria, as at Costerfield and Ringwood, but they are also found in Ordovician rocks, as at Sutton Grange, at Dunolly, and between Coimaidai and Gisborne. In any question of their origin, then, no importance could be attached to the association with Silurian rocks. Krausé mentions that the Costerfield ore has given assays as high as 9oz. gold and 80oz. silver per ton (5).

The other minerals found with the stibnite are not many nor abundant. Bournonite, cuproplumbite, and chalcostibite are noticed as rare at Costerfield (1). The few occurrences of scheelite in Victoria are not in association with the antimonial ores, though this mineral is found with them at Hillgrove, N.S.W.

Cervantite is the common alteration product of these ores, but kermesite and senarmontite are found in small quantity at a few places, and valentinite somewhat more frequently.

4. Chalcopyrite.—This mineral again is in small quantity in the ordinary type, though it frequently appears with increasing complexity. At the Thompson River Copper Mine it occurs with other copper minerals. A series of assays from this mine (13) showed only a trace of gold, and silver only as high as 6oz. per ton. It is noteworthy that these ores contain up to $3\frac{3}{4}$ per cent. nickel.

While this ore must then be regarded, so far as these assays go, as not a gold producer, it will be seen by examples already quoted that the addition of chalcopyrite to the minerals of the ordinary reef is at least sometimes favourable, though there is nothing to show that the increase in gold is derived from the chalcopyrite.

5. Siderite-chalcopyrite.—A vein composed mainly of these two minerals, with smaller quantities of pyrite, arsenopyrite.

galena and stibnite is described by Ulrich as forming a casing in a claim on the Eaglehawk Reef, Maldon (1). It assayed 17 per cent. copper and 45oz. gold per ton. On occount of the marked difference in the gold contents and the mode of occurrence I place this separate from the Thompson River ore. It approaches most nearly some of the dolomite veins which occur in the first group, but differs in the prominence of chalcopyrite.

6. Pyrrhotite chalcopyrite.—The association of these two minerals with one another is well-known in some important copper-mining localities. In Victoria they often occur in the quartz reefs, but I find no example of their occurrence in important quantity apart from other groups. They appear together as an addition to the groups. At Bethanga the addition of these two minerals to the minerals of the first group produces an ore in which copper is present in important quantity (6). At Maldon the two minerals are recorded by Moon more often from the same mine than separately (10). At Mt. William, in the Grampians, as described below, they occur with the minerals of the next group, but the comparison with mineralogically similar occurrences in the Gong Gong granite near Ballarat indicates that they may be regarded as independent. At the Gong Gong reservoir small quantities of pyrrhotite and chalcopyrite occur in the granite of a small quarry, and molybdenite is found in the same granite a mile away.

Evidence is wanting as to their influence on gold contents of the ore. At Cobar, N.S.W., these minerals with pyrite form the ore worked for copper and carry a little gold, but at a rate which would be worthless where these minerals only themselves form a small quantity of the ore.

The localities of these minerals together are mostly near granitic rocks, or where the rocks are somewhat altered. Pyrrhotite occurs at Piggoreet; here also the rocks are more schistose than usual in the bedrock of the Ballarat district, but the alteration cannot be due to the nearest granite area on the surface, as it is too far away. It seems more likely to be an outcrop of older rocks than usual.

Pyrrhotite occurs at Castlemaine and at Newstead. These also may be not far from granitic rocks.

The next three groups are found in or near the granitic rocks.

7. Molybdenite, usually with pyrite.—At McIntyre's a quartz reef contains these minerals. It is not noticed to be auriferous except on the indirect evidence that the alluvial gold of some gullies appears to start in its vicinity (14). This reef is 100 feet from the ill-defined McEvoy's Reef, from which three masses were obtained in close proximity to one another, and weighing about 800oz. each. Another reef on Mt. Moliagul contains the same two minerals, with the addition of arsenopyrite (14). It may be noticed that arsenopyrite is known as an accessory in the granite rocks at Morang.

At the Mt. William goldfield in the Grampians the gold was largely derived from the neighbourhood of one or more mineralised bands in the granodiorite. Part of the so-called alluvial was simply decomposed granodiorite in situ, carrying fine gold. This led to some remarkable views on the field as to the probable course of supposed deep leads. On these mineralised bands the quartz was in very thin veins for the most part, but at places hollow swellings occurred, lined with quartz crystals of a somewhat amethystine colour. In the alluvial there were many amethyst crystals and quartz crystals with marked zoned structure. The miners stated that the distribution of the gold was about that of the amethysts. Some of the claims worked decomposed seams in the granitic rock and were said to be obtaining payable results. The mineralised bands contained, with these small quartz veins and on joint plane without quartz, molybdenite with a smaller quantity of pyrite, and in some places chalcopyrite and pyrrhotite. Scheelite was also said to occur, but I obtained no certain information on this point. Though the undecomposed rock carrying these minerals was not being worked there can be little doubt that a great part of the gold at least was derived from such occurrences, as gold was being obtained in seams in the partly weathered rock, in thoroughly decomposed rock, and in alluvial, of which some of the characteristic constituents were clearly derived from such bands.

8. Bismuth minerals.—These were noticed by Ulrich from Kingower and elsewhere (1, 2). They occur also at Redbank

near Avoca; among those from this locality there is a little tetradymite. Bismuth minerals with traces of tellurium occur also at Mallacoota (4) and tetradymite is also recorded from Maldon (4). A part of the bismuth at Maldon occurs in the rare mineral maldonite (2). Native bismuth, bismuthinite, bismite and bismutite are recorded from Maldon.

9. Wolfram.—In the localities of which I have most detail this mineral is associated with one of the preceding groups, but it seems best to place it separately. There is no evidence of any influence on gold contents, and it would probably be of more value for itself if in quantity than for its influence on the gold.

The following examples show the minerals of the last three groups associated with one another.

Reef on Sandy Creek, Maldon.—Native bismuth, hematite, schorl and wolfram. No statement as to gold contents (1).

Reef on the Nuggetty Range, Maldon.—Quartz, orthoclase, schorl, mica, molybdenite, wolfram, scheelite. It is contained in granitic rock. Gold is not mentioned (2). Rock crystal and cairngorm occur in the cavities. Reefs of this kind are no doubt the source of the quartz crystals containing, in different instances, molybdenite, scheelite and schorl, which have been found in the neighbouring Bradford Lead.

Superb Reef, Linton, near the granite, contains bismuth, bismuthinite, bismutite, molybdenite, wolfram, besides quartz crystals containing schorl, and rutile (5).

It may be noticed that the supposed columbite at Maldon has been shown to be rutile (4), and that Ulrich records titanium dioxide from Steiglitz (2).

10. The material worked for mercury on the Jamieson River consists, in samples I have received, of a clay rock with quartz veins containing in both cinnabar and mercury. Gold is said to be present. Cinnabar is also recorded from near Bullumwaal, found in small broken fragments on the surface near a quartz reef (4).

Campbell's Reef, Moyston, is mentioned by Ulrich (2) as containing strong irregular veins and patches of calcite, sometimes with galena and pyrite (2). It would seem most likely that these are analogous to the dolomite veins and patches at Ballarat and other places, and it need not be for this reason separated from the first type.

Manganese oxides are sometimes abundant in the outcrops of quartz reefs. A source of this manganese is not always evident. In some cases, as at Linton, it may be derived from wolfram. Sphalerite may also contribute to it. One analysis of psilomelane from Maldon showed nearly 3 per cent. cobalt oxide. Rhodochrosite is recorded from Clunes (1). A pink mineral in a very thin layer or film is sometimes found at Ballarat, but examination showed neither manganese nor cobalt.

I have in my possession a sample of zinc from Bamganie, said to have been obtained in workings in the 80ft. level of one of the mines. There was nothing in the circumstances under which I obtained it to suggest any doubt as to its genuineness.

I have attempted this classification of the auriferous deposits with a view to arranging the more important parts of our present information, and to suggest a basis for more complete and more systematic observations in the future. Where old records are quoted without any explicit reference they are contained in Atkinson's List of Victorian Minerals (3), and in Walcott's Additions (4). These papers have greatly facilitated the work of this classification.

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